An Introduction to the Mars Atmospheric Trace Molecule Occultation Spectrometer (MATMOS)

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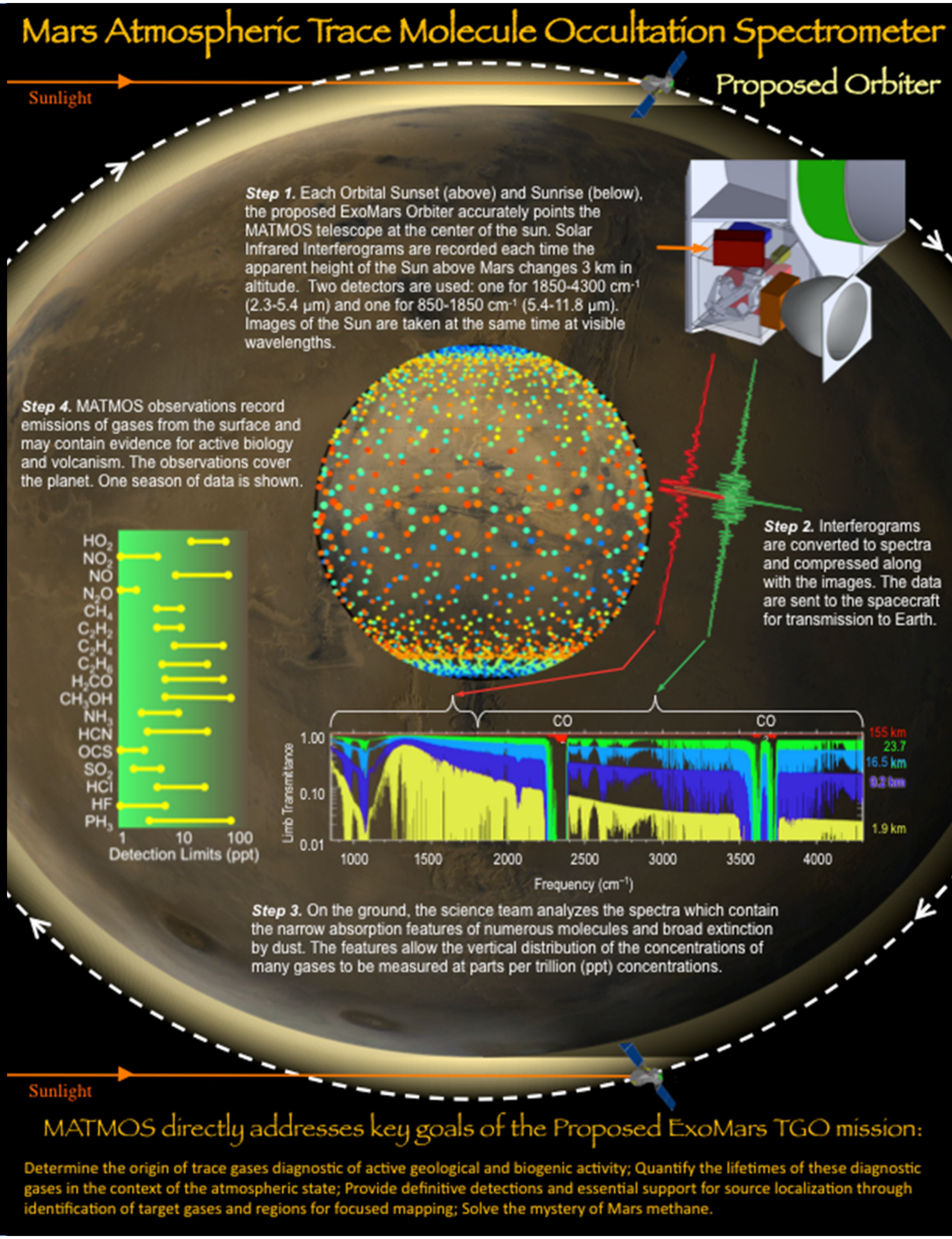
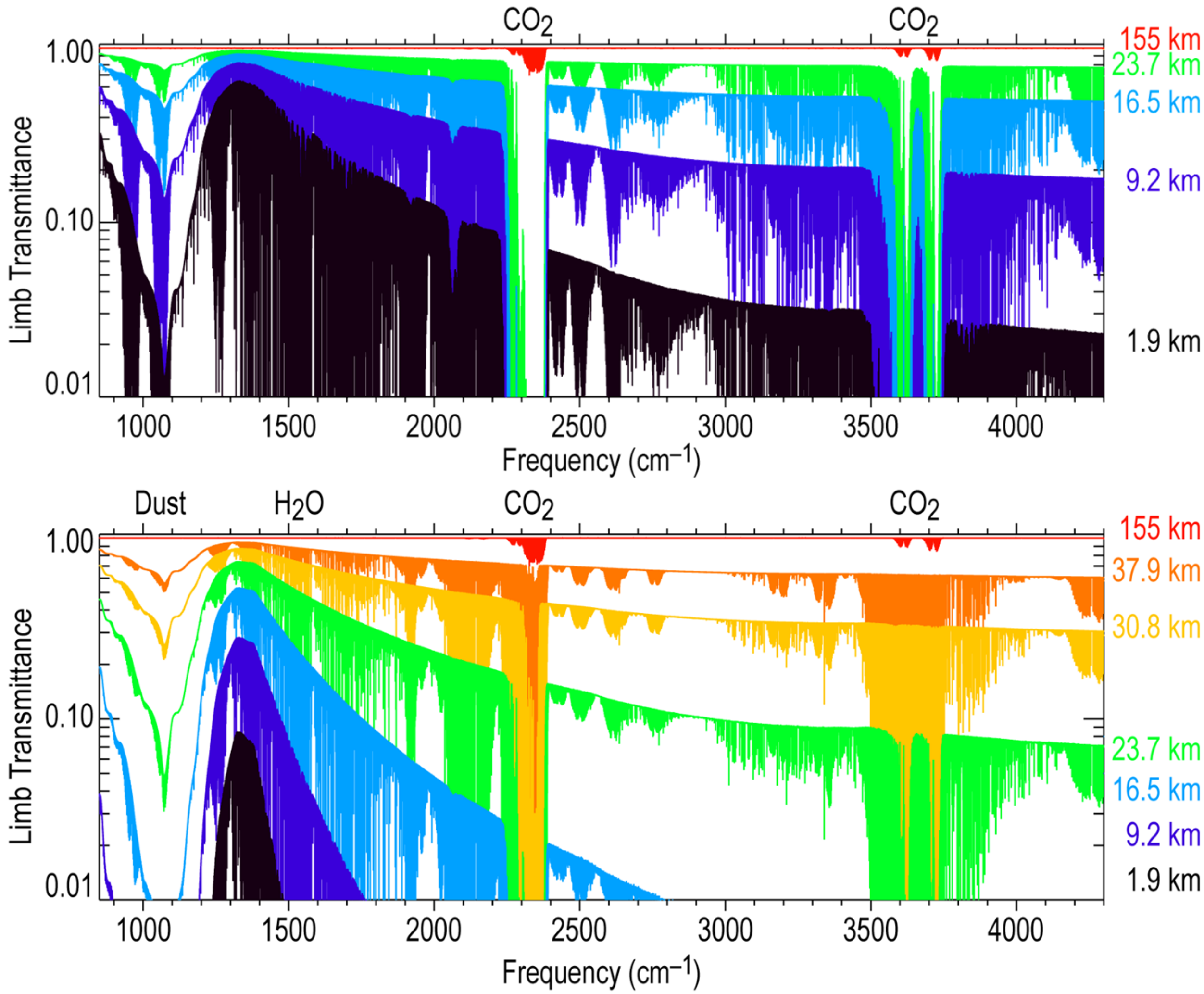

Mars Atmospheric Trace Molecule Occultation Spectrometer
Proposed Orbiter
Sunlight
Step 1. Each Orbital Sunset (above) and Sunrise (below), the proposed ExoMars Orbiter accurately points the MATMOS telescope at the center of the sun. Solar Infrared Interferograms are recorded each time the apparent height of the Sun above Mars changes 3 km in altitude. Two detectors are used: one for 1850-4300 cm-1 (2.3-5.4 μm) and one for 850-1850 cm-1 (5.4-11.8 μm). Images of the Sun are taken at the same time at visible wavelengths.
Step 4. MATMOS observations record emissions of gases from the surface and may contain evidence for active biology and volcanism. The observations cover the planet. One season of data is shown.
Step 2. Interferograms are converted to spectra and compressed along with the images. The data are sent to the spacecraft for transmission to Earth.
HO2
NO2
NO
N2O
CH4
C2H2
C2H4
C2H6
H2CO
CH3OH
NH3
HCN
OCS
SO2
HCl
HF
PH3
1
10
100
Detection Limits (ppt)
CO
CO
1.00
0.10
0.01
Limb Transmittance
1000
1500
2000
2500
3000
3500
4000
Frequency (cm-1)
155 km
23.7
16.5 km
1.9 km
Step 3. On the ground, the science team analyzes the spectra which contain the narrow absorption features of numerous molecules and broad extinction by dust. The features allow the vertical distribution of the concentrations of many gases to be measured at parts per trillion (ppt) concentrations.
Sunlight
MATMOS directly addresses key goals of the Proposed ExoMars TGO mission:
Determine the origin of trace gases diagnostic of active geological and biogenic activity; Quantify the lifetimes of these diagnostic gases in the context of the atmospheric state; Provide definitive detections and essential support for source localization through identification of target gases and regions for focused mapping; Solve the mystery of Mars methane.

Science Traceability Matrix

TGO	MATMOS Objectives	Measurements	Instrument Requirements	Mission Requirements
JIDT #1: Trace Gas Detection	***Obj. 1:*** Search for atmospheric chemical tracers of geological and biogenic activity.	Coincident measurements of diagnostic gases and their isotopic distribution at ultra high sensitivity.	• High signal-to-noise ratio (SNR): SFTIR geometry, cold detectors • Broad spectral range (850–4300 cm^{-1}) • Spectral-line resolving resolution (0.02 cm^{-1}) • Data volume/spectrum: 2.88 Mbits	• Stable spacecraft platform: (~0.5 mrad pointing accuracy to point at center of solar disk; <0.3 mrad drift during occultations) • Radiator pointing to dark sky at all times
	Obj. 2: Quantify the lifetimes of diagnostic gases and establish the role of heterogeneous chemistry.	• Coincident profiles of diagnostic gases, oxidants, dust, ice, and temperature (0–75 km at 3 km resolution) • 4-band visible images at 200 m/pixel with 7 mrad FOV (image the full sun) • Global coverage (regional ~ 4° lat. and 8° lon) • One Mars year for full seasonal coverage	As above, plus: • 3 km vertical resolution (1.5 mrad FOV; 2–6 s adjustable scan speed) • Visible solar imager boresighted with FTS • FTS data/occultation: 109.4 Mbits (uncompressed) • Image data (60 × 60 pixels): 42 kbits/band (uncompressed) • Onboard processing (compression)	As above, plus: • Spacecraft location knowledge • Alignment knowledge (spacecraft axes): 0.05 mrad • 350–420 km, ~74° inclined orbit for rapid variation in occultation latitude • Observations over one year; 24 occultations/day • 1900 Mbits/day downlink
JIDT #2: Characterization	***Obj. 3***: Quantify the exchange of water, CO_2 and their isotopologues with the surface and cloud providing unique insight into atmospheric cycles of CO_2, dust and water.	• Coincident global vertical profiles from 0–75 km at 3 km resolution of volatiles, dust, temperature, and pressure. • Volatile isotopologues.	As above.	As above.
	Obj. 4: Understand upper atmosphere coupling toward improving the description of atmospheric escape.	Global vertical profile measurements of temperature and pressure from 0–200 km.	As above, plus additional data volume for 100–200 km altitude: 11.5 Mbits/occultation	
JIDT #3: Localization	***Obj. 5:*** Provide essential support to localization campaigns.	• Global maps of trace gases at regional scales. • Validation of mapping instruments.	As above.	
	Obj. 6: Solve the mystery of Mars methane.	Same requirements as Obj.1–5.		

Calculated Mars Limb Transmittance Spectra

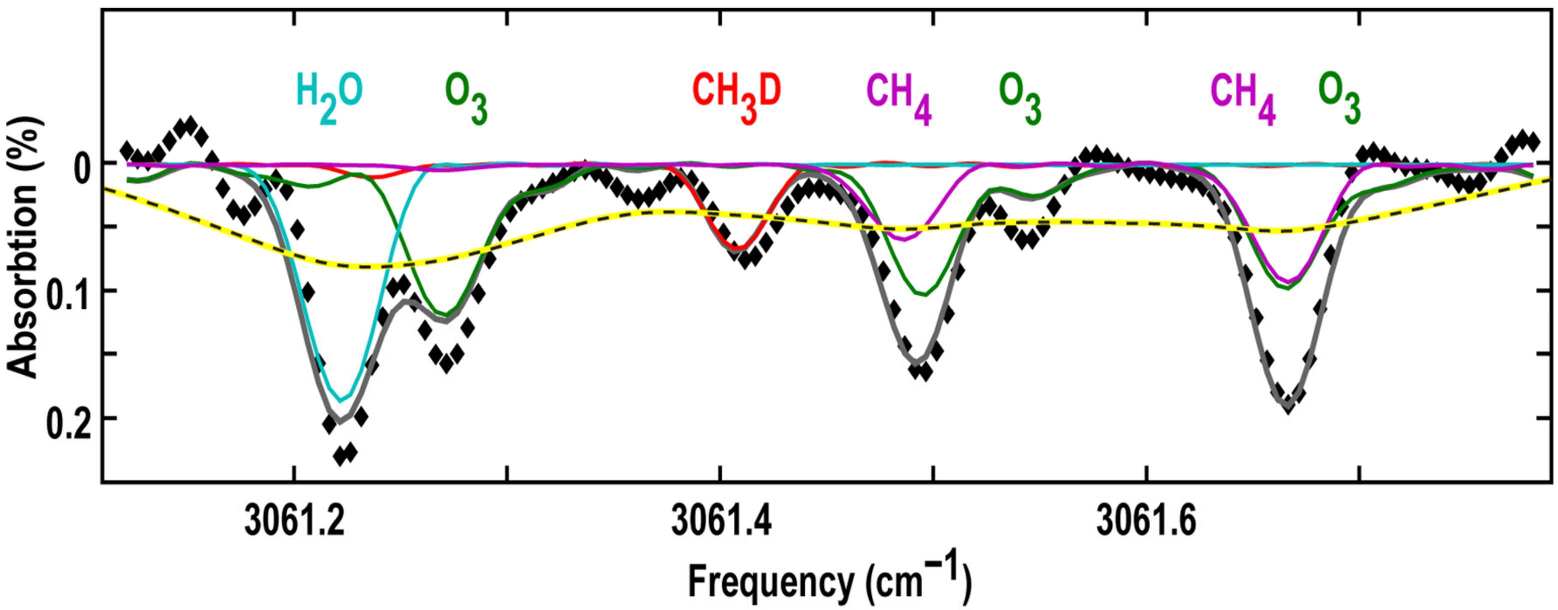


τ Dust = 0.1

τ Dust = 0.6

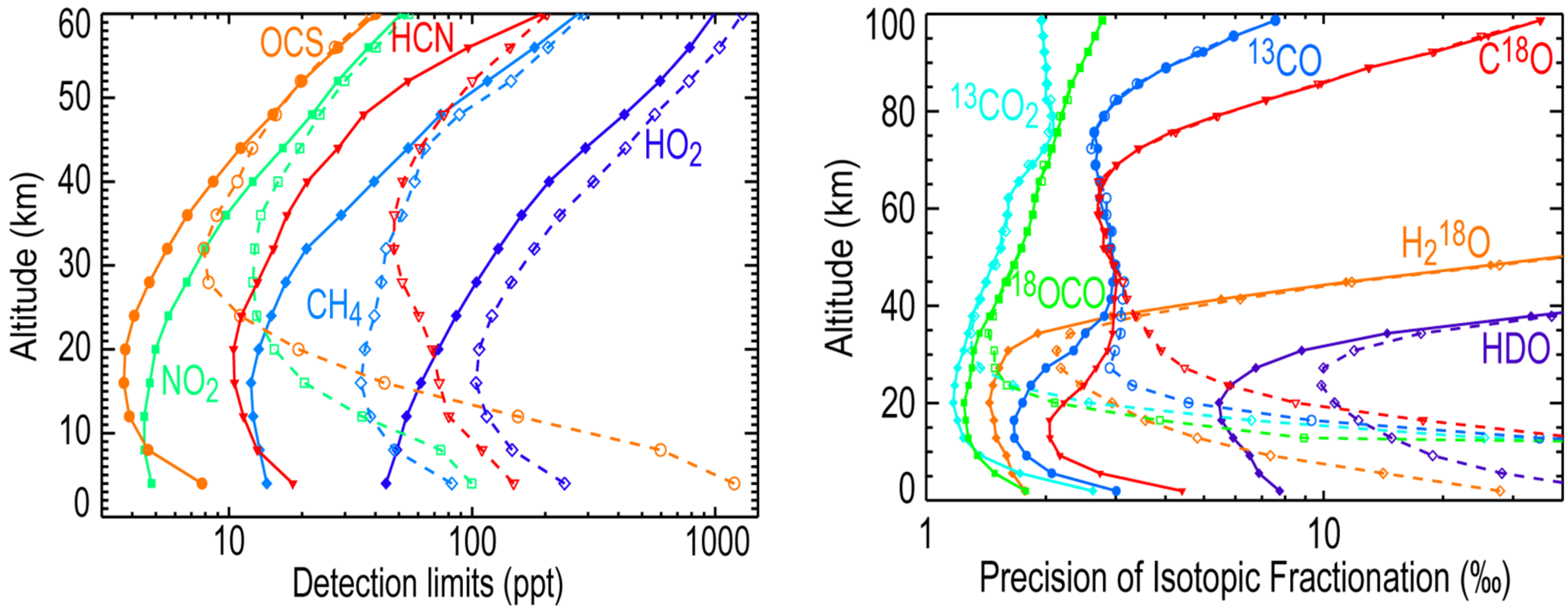
With extra atmospheric spectra obtained on each occulation, the SFTIR technique yields a series of self-calibrated limb transmittance spectra spaced by a few km

SFTIR – Terrestrial Example



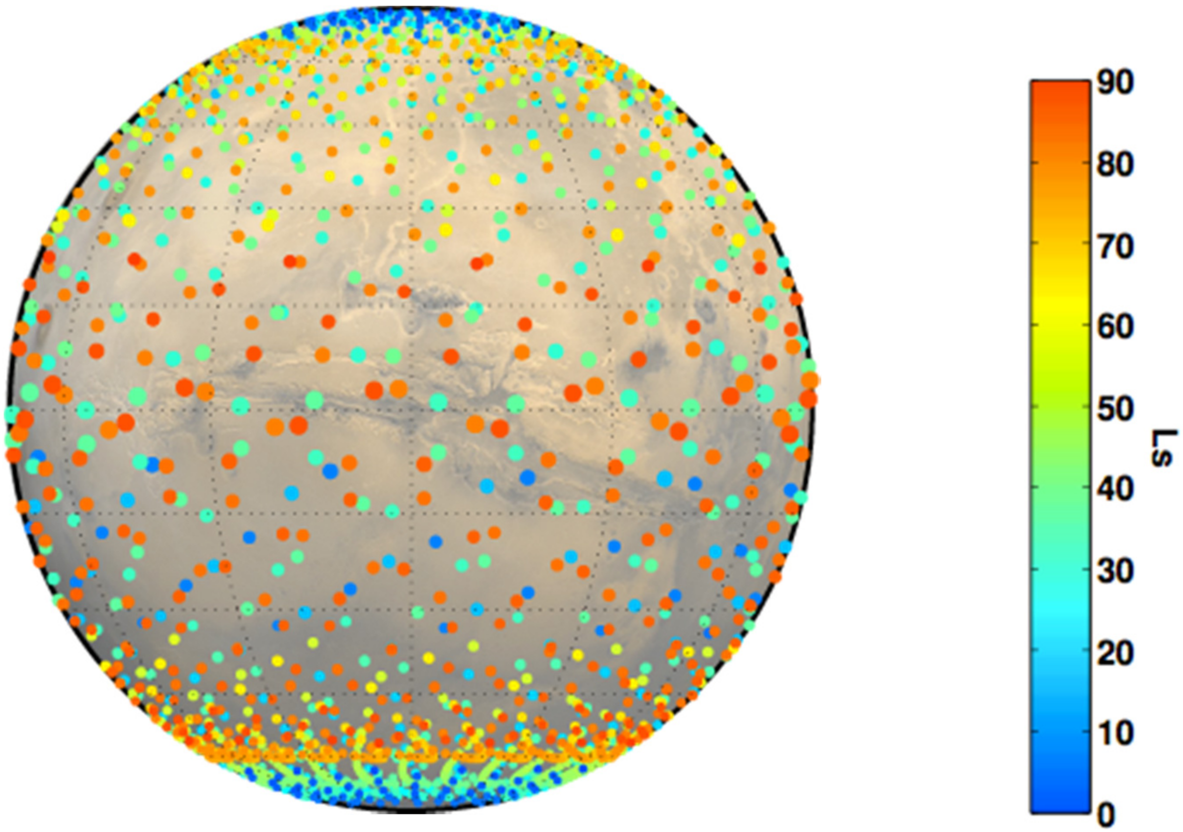
The average of 189 spectra acquired at ~50 km altitude in the Earth's stratosphere by ACE-FTS (tangent pressure 0.8 mbar), illustrate the capability of SFTIR for trace gas detection. The black points are the data; the gray line shows the fitted calculation using the retrieval code that will be adapted for MATMOS. This small region (less than 0.04% of the total spectral range of MATMOS) is one of dozens in which CH_4 can be measured. The spectra are fit to 0.02%, consistent with photon source noise limited performance (single spectrum SNR of 350:1). For comparison, the individual gas absorption features would not be resolved using a lower resolution spectrometer such as SOIR on Venus Express (yellow).

L2-B Trace Gas Retrievals



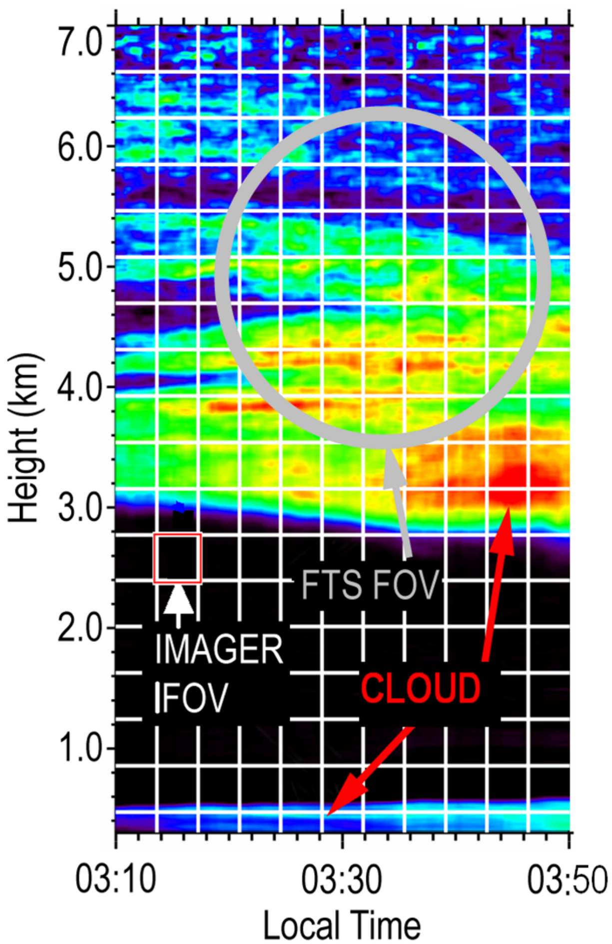
MATMOS will produce profiles of the concentrations of numerous trace gases and the isotopic abundance of CO, CO_2, and H_2O to high altitude. Shown is the expected performance for 100 occultation average under low ($\tau = 0.1$, solid) and high ($\tau = 0.6$, dashed) dust opacity. The graphic table on the Fact Sheet illustrates the limits of detection for trace gases under high (right end of bar) and low (left end of bar) dust averaging 100 occultations over all altitudes.

L3 – Observations Over One Season



With the planned EMTGO orbit as describe in the E-PIP, occultations would be observed at all latitudes each season.

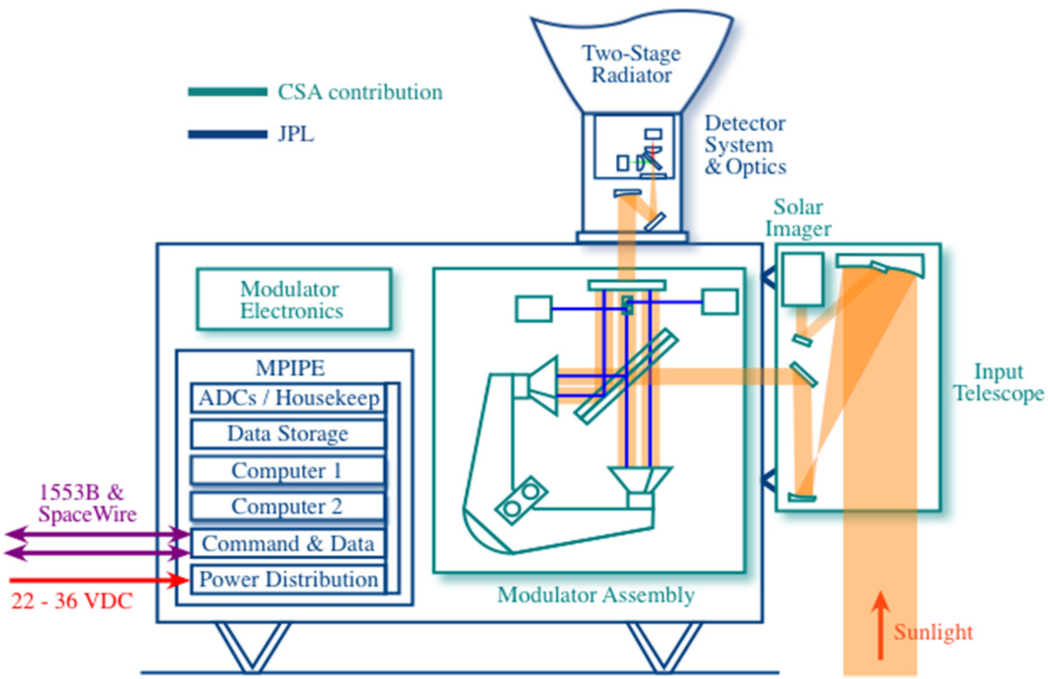
Visible Images



The MATMOS imager, bore sighted with the FTS resolves structure within the extended FTS FOV (~3 km). These thin cloud layers were observed by Phoenix for ~30 min. near dawn. Colors represent LIDAR backscatter. Each spectrum would be accompanied by an image of the extended field of view. The imager would allow the pointing of the space craft to be evaluated.

With four colors, the imager in combination with the IR spectra would allow the optical properties of dust and cloud to be determined.

MATMOS Block Diagram

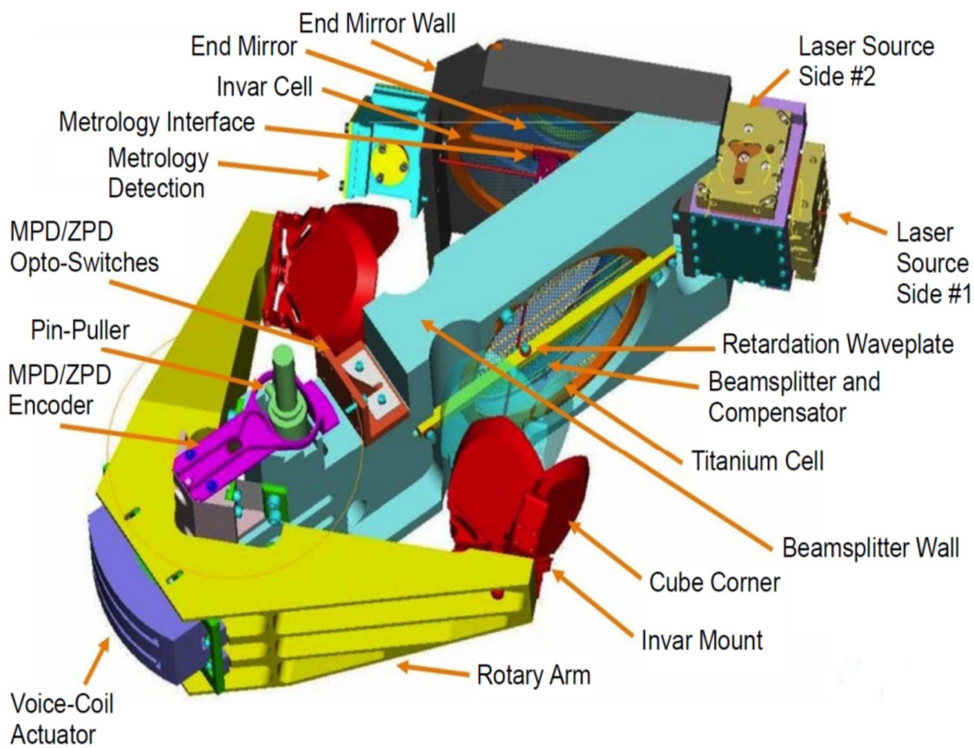


A small telescope is used to bring sunlight into the interferometer. MATMOS itself has no active pointing capability and so relies completely on the s/c to couple the center of the sun into the instrument.

The modulator (next slide) couples the sunlight onto the detectors mounted on the cold stage of the passive radiator.

Extensive onboard processing is required to compress - by 100 fold - the raw interferograms to spectra for transmission to s/c and Earth. Downlink is ~1.9 Mbits / day.

MATMOS Interferometer

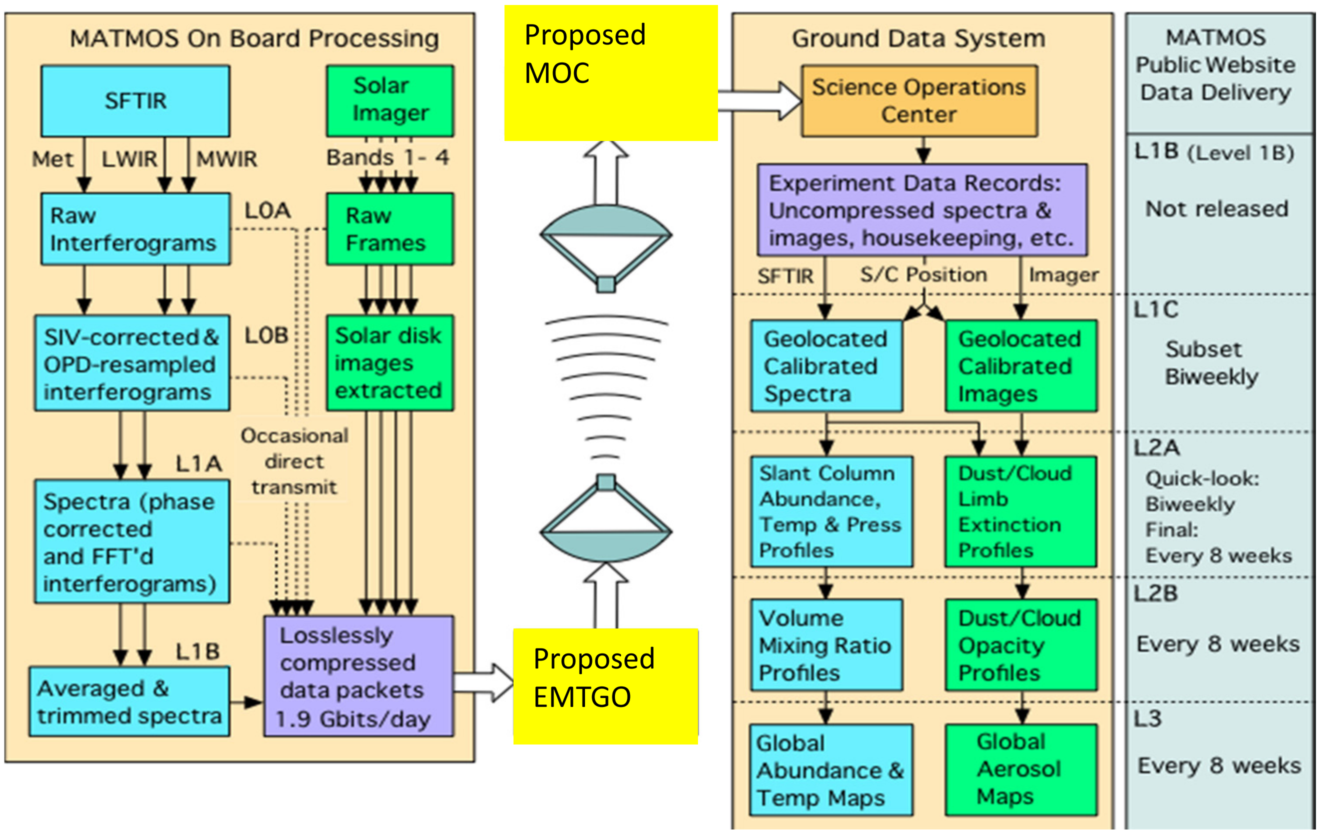


The core of MATMOS is the interferometer, manufactured by ABB Bomem and contributed by the Canadian Space Agency. The interferometer is based on the ACE-FTS design, updated for parts obsolescence and with improvements made for the GOSAT TANSO interferometer.

The FTS and Imager Subsystem

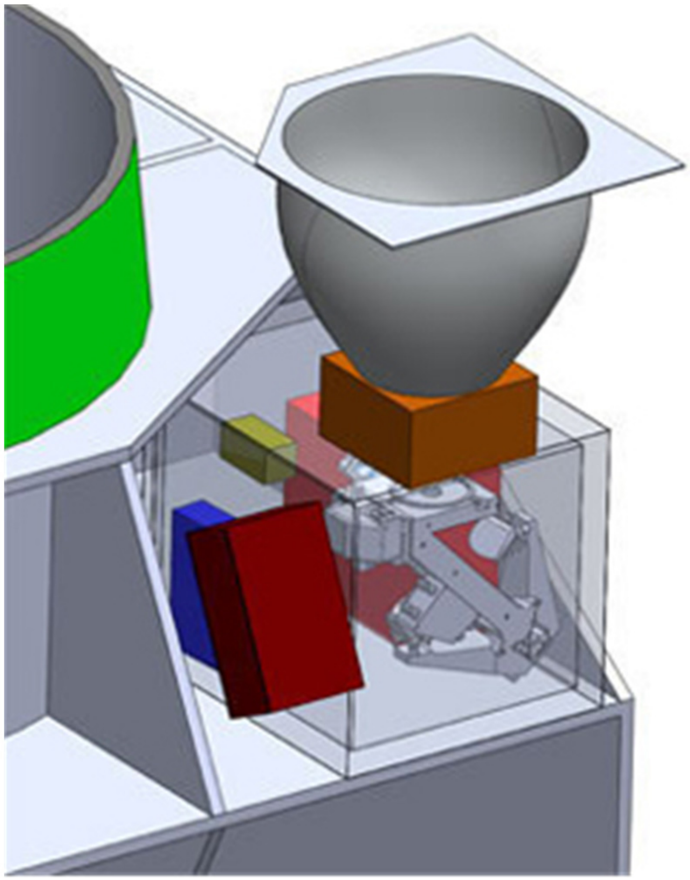
	Instrument Parameter	Value
FTS Performance	IR spectral range	850–4300 cm^{-1} (2.3–11.8 μm)
	Spectral resolution	0.02 cm^{-1}
	FOV	1.56 mrad circular (~3 km vertical resolution at limb)
	Input aperture	80 mm
	Detectors	HgCdTe and InSb PV: Source-photon-noise limited
	SNR	>250
	Rate of acquisition	6 speeds; 2–6 secs / spectrum (depending on orbital beta-angle)
	FTS signal sampling	24 bits @ 215 to 645 kHz (depending on scan speed)
Imager Performance	Image spectral bands	312, 512, 650, and 1020 nm
	Image FOV	~7 mrad (10 km × 10 km), boresighted with FTS to 0.05 mrad
	IFOV	~0.115 mrad (~0.2 km)
	Image size	60 × 60 pixels / Spectral Band @ 12 bits
	SNR	>1000
Data	Data processing (onboard)	Phase correction, SIV correction, FFT, averaging, compression
	Data volume	1900 Mbits/day
Environmental	Thermal	Detectors at ~90 K using radiator pointed to dark space
Integration	Alignment	Spacecraft boresight knowledge to <0.05 mrad
Physical	Mass	38 kg (CBE); 42 kg with E-PIP margin
	Power	51.4 W (CBE); 57.3 W with E-PIP margin (worst case)
Spacecraft	Pointing	Spacecraft sun pointing to <0.5 mrad during occultations

Proposed Data Flow from MATMOS



As proposed, MATMOS will generate very large data volumes (~200 Gbits/day). These are compressed by 100-fold before transmission to Earth. The Level 1C−3 processing occurs on the Ground Data System. Level 1C (calibrated spectra and images), Level 2B (geolocated spectra and images) and Level 3 (global maps) are produced by the IPAC on the Caltech campus. Interferograms and raw images are occasionally downlinked and made available as special data products. Level 1B−3 products are delivered to the PDS every three months subject to the proposed ExoMars TGO Data Management and Archival Requirements.

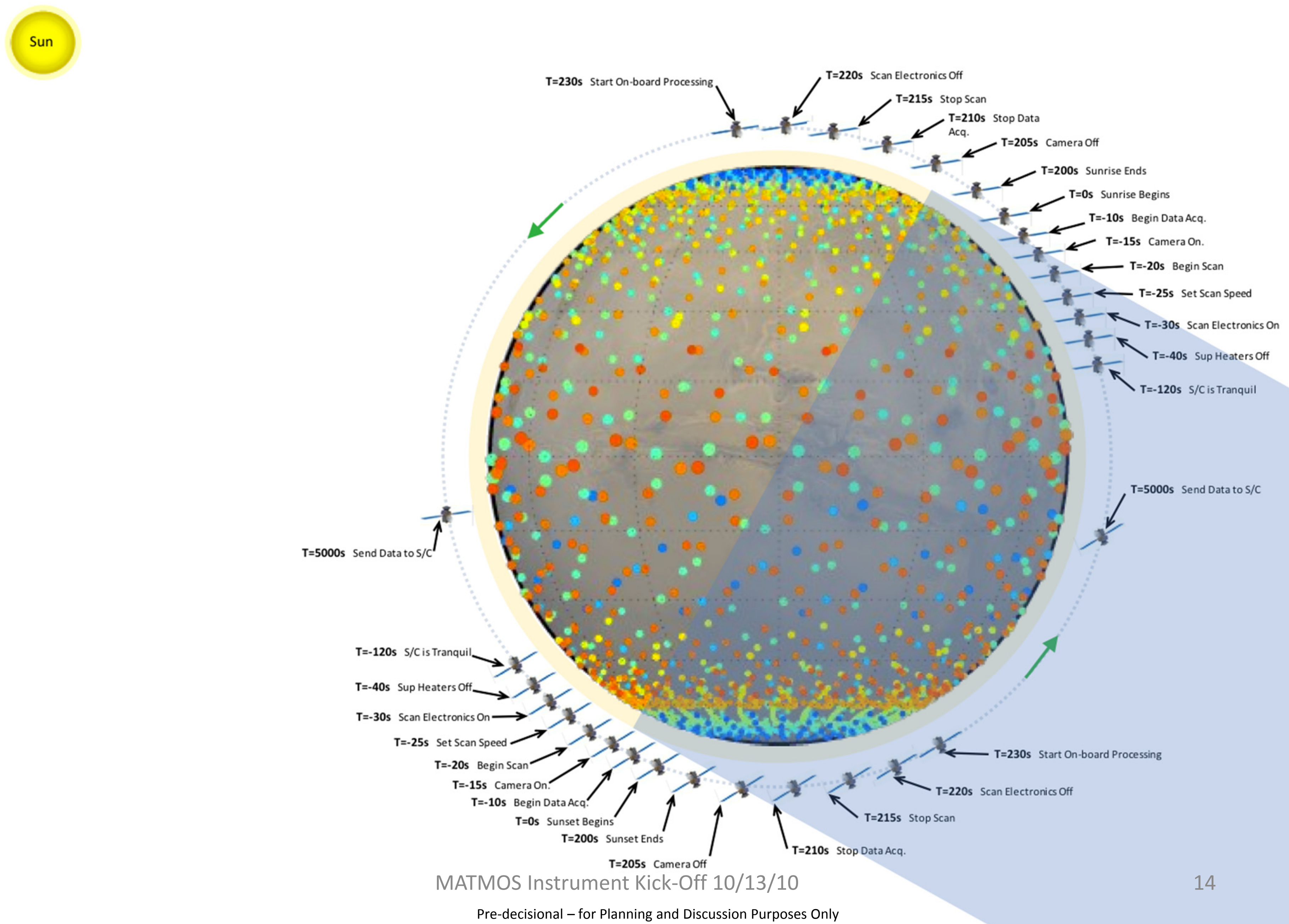
MATMOS on the Proposed EMTGO



This sketch shows MATMOS in its baseline location on the corner of the Orbiter Module sun deck. During the Science Phase this position would provide a view of cold space for the cryoradiator, to cool the IR detectors mounted directly below (before EDM separation the EDM would partially block the radiator FoV.) It would also provides a LoS from the instrument telescope to the Sun during sunrise/sunset.

There are several mechanical accommodation options for the radiator, which consider performance and EDM clearance. Here the radiator boresight is shown aligned with the X-axis.

Operations – a Proposed MATMOS / EMTGO orbit



Summary (I)

MATMOS is a ***detection*** instrument, but would provide characterization of atmospheric chemistry and aerosol, and low resolution mapping to support EMTGO localization efforts

- Sensitivity under both dusty and clear conditions aided by the broad spectral coverage and source noise limited performance:
  - The 1300 cm^{-1} methane band, for example, provide good SNR to 1.9km altitude under high dust (tau 0.6) while other bands perform better under low dust conditions.
  - Planned retrieval effort for 19 new trace species and isotopologues
  - Small amount of averaging (a few days of observations) would be required to meet detection limits described above; thereafter, focus is on latitudinal and seasonal change and characterization

- Inclination:
  - 74 degrees gives global coverage in 8 weeks at 4 × 8 degrees.
  - Change of +/- 10 degrees causes loss of regular low latitude coverage.
  - Planned spatial coverage gives ‘maps’ of trace species at time intervals which could be useful operationally.

Summary (II)

- Pointing knowledge of 0.5 mrad:
  - with FTIR FOV gives 3km vertical resolution in the lower atmosphere, needed to give good estimates of chemical lifetimes due to variability of vertical aerosol structure;
  - Transformed ephemeris data needed from SOC in order to produce vertical profiles and maps
- Alignment knowledge of 0.05mrad wrt spacecraft/other payloads:
  - Corresponds to one pixel of solar imager
  - Solar imager can be used to 'calibrate' spacecraft pointing
- Data:
  - Budget of 1.9Gbits assumes interferograms would be processed to spectra on board and compressed. In routine operations, interferograms would be overwritten before they could be analysed on the ground; we do intend minimal download of raw interferograms to confirm accuracy of on-board data reduction.
  - Data to be made available to the public within 8 weeks of downlink (following commissioning phase).
  - Data to be made available to the EMTGO payloads rapidly.

Questions?

Backup Slide:
MATMOS Data Processing Timeline